Plasma flow and impurity transport around the neutraliser plates of the Tore Supra Ergodic Divertor.

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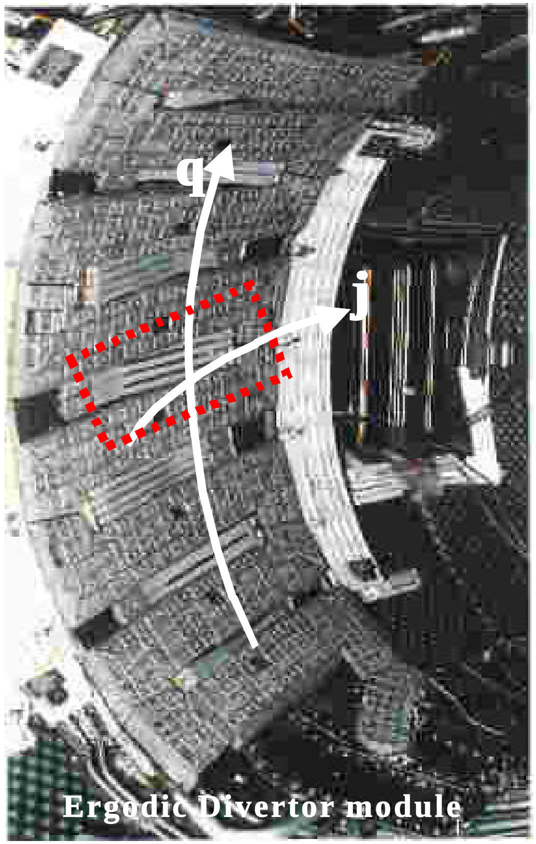
1. Abstract

Two-dimensional (2D) modelisations of the deuterium recycling process close to a neutralizer plate of the Tore Supra Ergodic Divertor from the recycling code ED-COLL [1] are used to calculate the Mach number and the electric field distribution in this area. These calculations are first, compare to the Gundestrup probe radial measurements. In most of the case, we find a good agreement between simulation and measurement. Applying this model to an equatorial neutralizer plate, we find that, consistently with the geometry of the connection of field lines at the edge, a relatively weak flow reversal of the background plasma is possible at the leading edge of the neutralizer. Then, we used these results to modell impurity transport close to the neutralizer plates of the ergodic divertor with the 3D Monte Carlo code BBQ [2]. The results are discuss and used to interpret spectroscopic datas.

CONTEXT

Understanding impurity screening and core contamination requires to study the carbon production, radiation and transport close to the neutraliser plate of the Tore Supra Ergodic Divertor



Diagnostic tools are:

4 Optical fibers

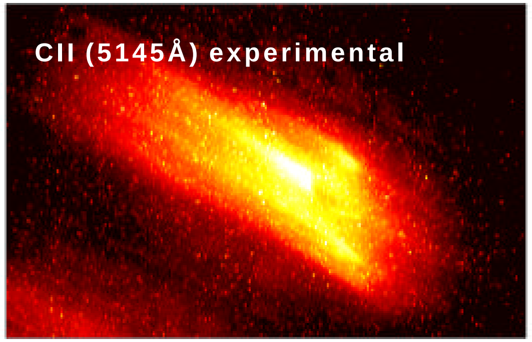
1 Visible CCD camera

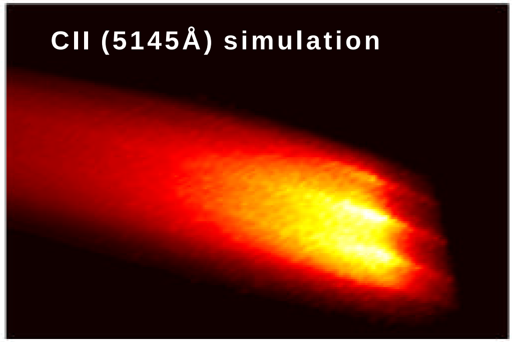
1 Gunderstrup probe

Modelling tools are :

The 3D Monte carlo code BBQ for the carbon production and transport

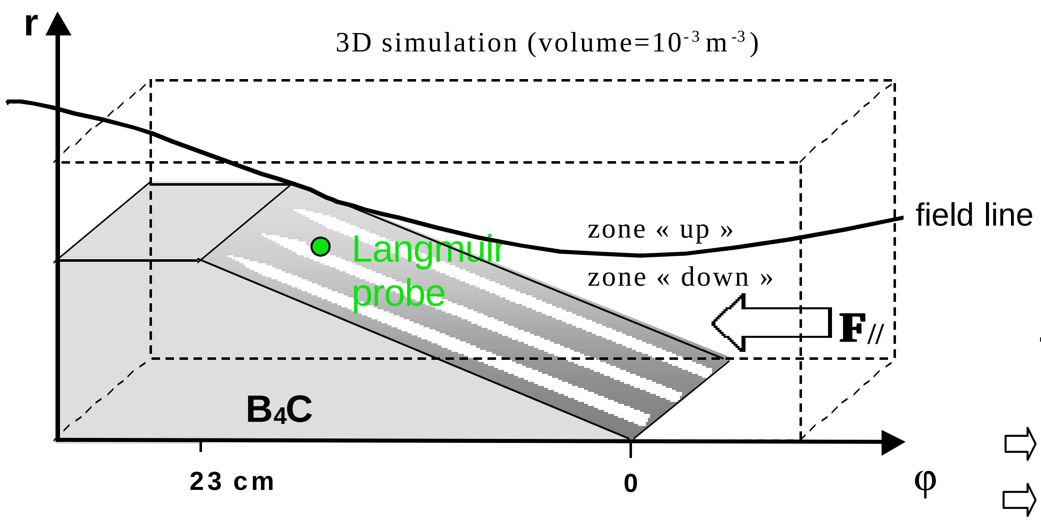
The multi-1D code EDCOLL for the recycling





RESULT : Simulated and measured pictures

IMPURITY PRODUCTION AND TRANSPORT (BBQ



The magnetic configuration is calculated with the field line tracing code MASTOC

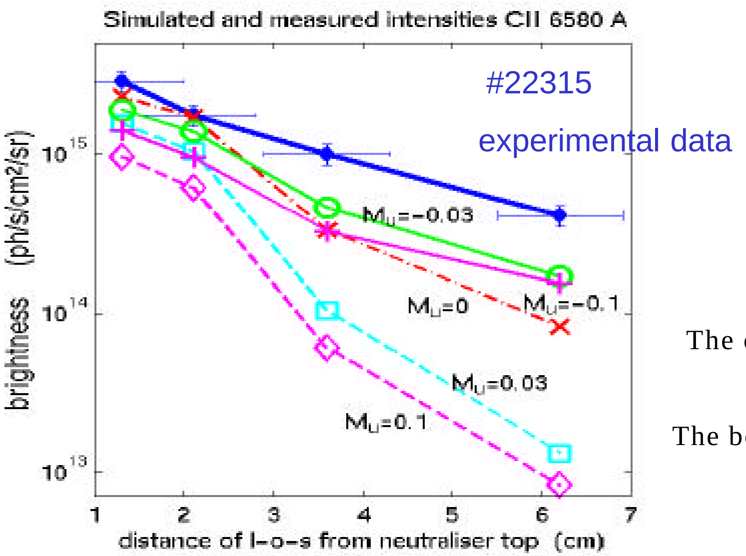
The temperature and density distributions are built from Langmuir probe measurements and with a field line penetration model

Physical, chemical and self -sputtering mecanisms are considered separately

The simulations show that the impurity transport is strongly influenced by two important parameters.

- The parallel velocity of the background plasma: $v_{//}=M_{//} \cdot c_s$
- The parallel electrostatic field $E_{//}$

comparison with experiment



The comparison is made with four optical fibers radially spaced

The best simulation is obtained with $M_{//}$ weak in the zone « up »

Simulation shows that:

Emission profiles depend strongly upon $M_{//}$ and $E_{//}$

PLASMA FLOW AND RECYCLING (EDCOLL)

1/ Plasma flow

convergence

ED-COLL (Φ_{inc} + T_e + n_e)

↓

ionisation source

↓

Mach number calculation → $$\frac{M_{//}(r,x)}{1+M_{//}(r,x)^2}-\frac{M_{//}(r,x_0)}{1+M_{//}(r,x_0)^2}=\frac{1}{n_e^{stagn}(r)\cdot c_s(r)}\int_{x_0}^{x} S_i(s)ds$$

↓

Density distribution → $$n_e(r,x)=\frac{n_e^{stagn}(r)}{1+M_{//}(r,x)}$$

↓

$M_{//}$ & n_e

THE CALCULATION IS DONE IN A LIMITED REGION OF SPACE. THEREFORE:

Te is assumed to be constant along a field line

The cross-field transport is neglected

Viscosity is neglected in the calculation of the flux pattern

2/ Ionisation source

input: $n_e^{stagn}(r)$

$T_e(r)$

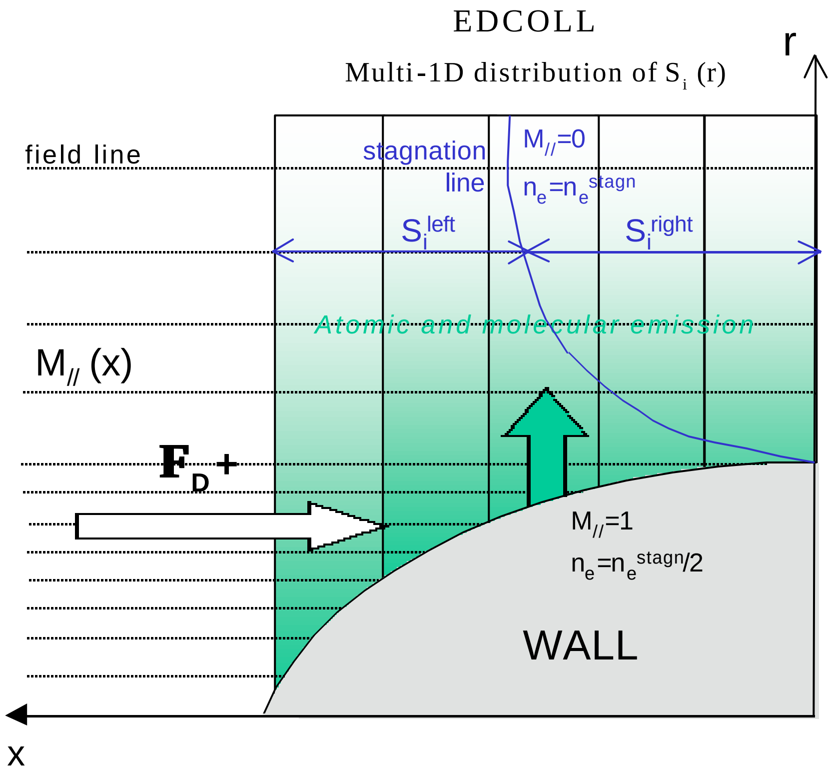
output: Atomic and molecular distributions ; ionisation source $S_i(r,x)$

3/ Electrostatic potential

$$V(x,r)=-\frac{k_b T_e(r)}{e}\cdot \mathrm{Ln}(1+M_{//}(x,r)^2)+V^{stagn}(r)$$

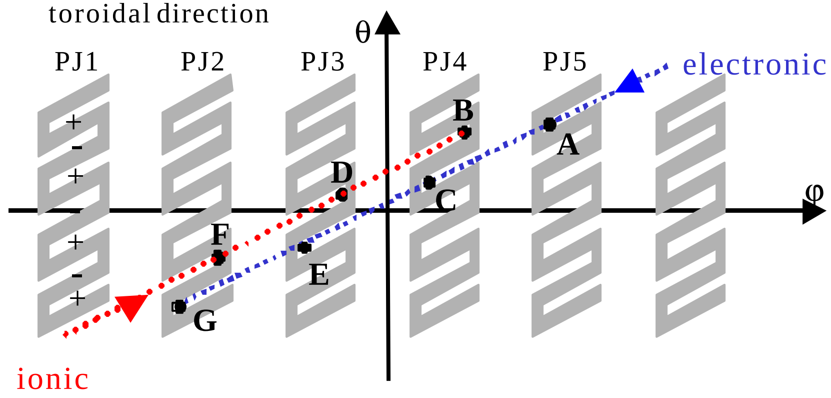
$$V^{stagn}(r)\approx\frac{k_B T_e(r)}{e}\cdot \mathrm{Ln}2$$

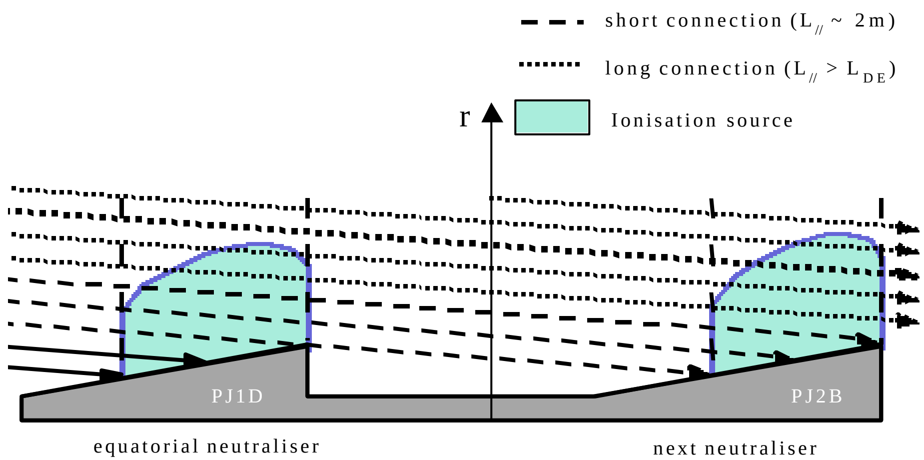
$$E_{//}(r,x)=\nabla_{//}V(r,x)$$



MAGNETIC STRUCTURE

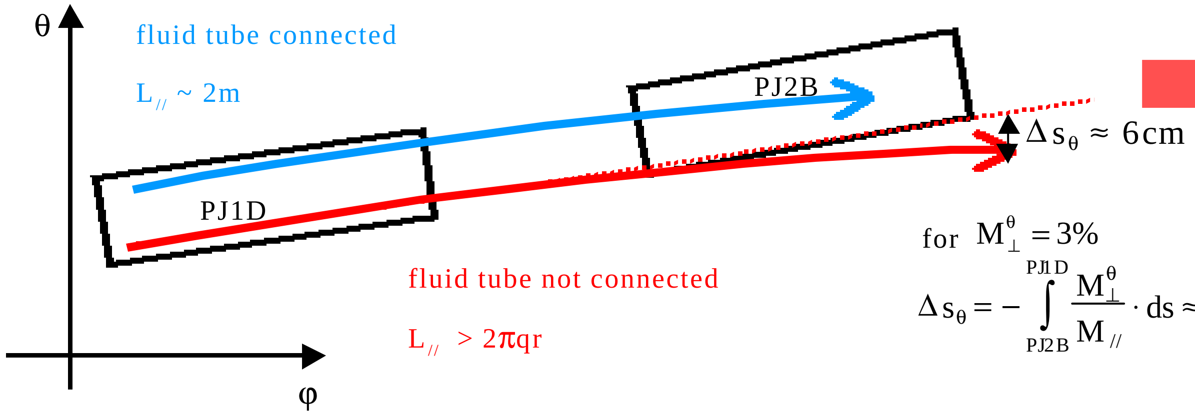
The ED of Tore Supra is composed by 6 modules equally spaced in the toroidal direction





The connection to the following NP influence the plasma flow distribution in the zone « up »

Due to the magnetic shear and to the E×B drifts, the real situation is less simple: only a limited part of the flux tube passing above a neutraliser is connected to the next one



for $M_\perp^\theta = 3\%$

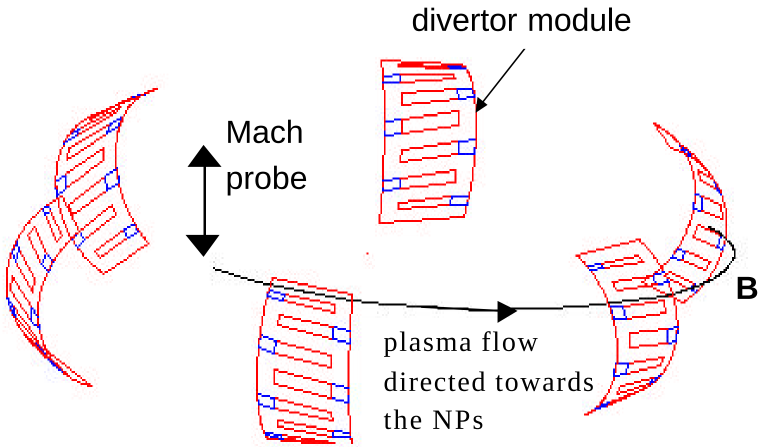
$$\Delta s_\theta = -\int_{PJ2B}^{PJ1D} \frac{M_\perp^\theta}{M_{//}} \cdot ds \approx 6\text{cm}$$

Two different situations:

1. **short connection** (blue line) $M_{//}$ close to 1 in zone « up »

2. **long connection**, (red line) $M_{//}$ small(0 or slightly <0) in zone « up »

SIMULATED AND MEASURED PLASM FLOW



Good agreement between calculations and Gunderstrup measurments for both the parallel Mach number and integrated source, validating the model assumptions.

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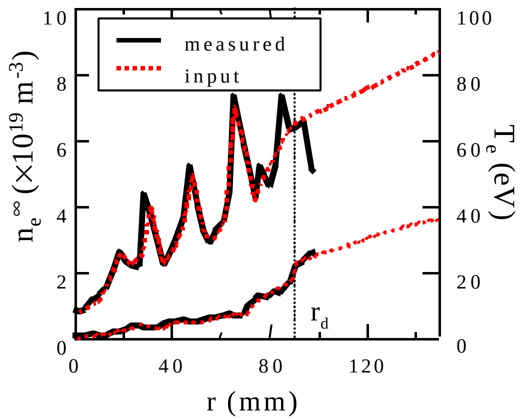
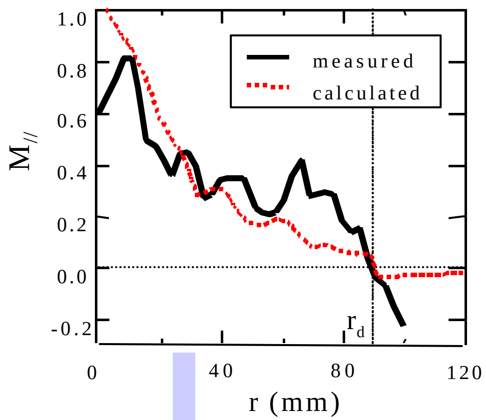
I_p=0,75 MA ; I_{DE}=18 kA ; q_{bord}=3

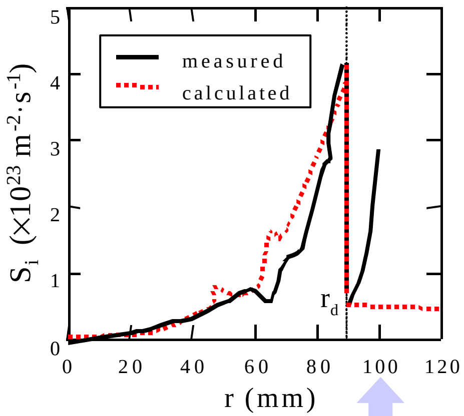
Input for calculation



plasma flow

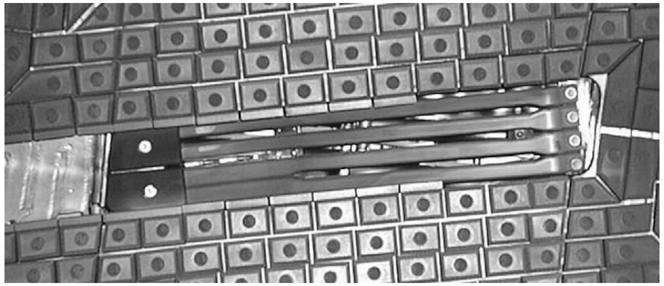


ionisation source



$$S_i^{exp}(r) = \frac{n_e^{\infty}(r)\cdot c_s(r)}{2}\cdot\left[1 - M_{//}^{exp}(r)\right]^2$$

PLASMA BACKGROUND CLOSE TO PJ1D



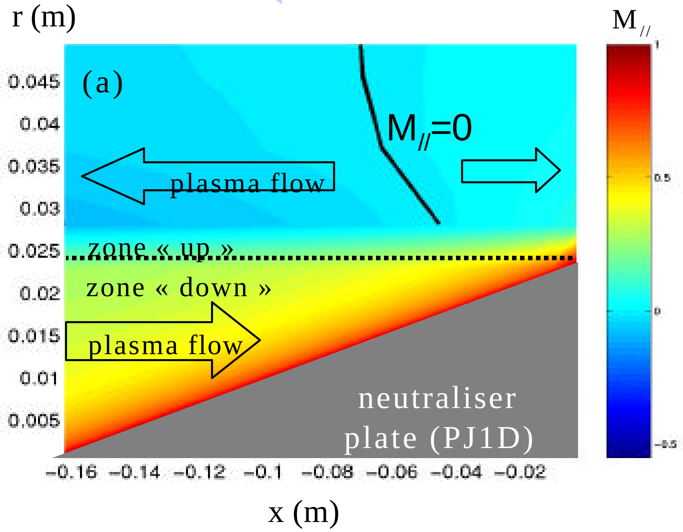
plasma flow and impurity transport are modelled close to the equatorial neutraliser plate PJ1D

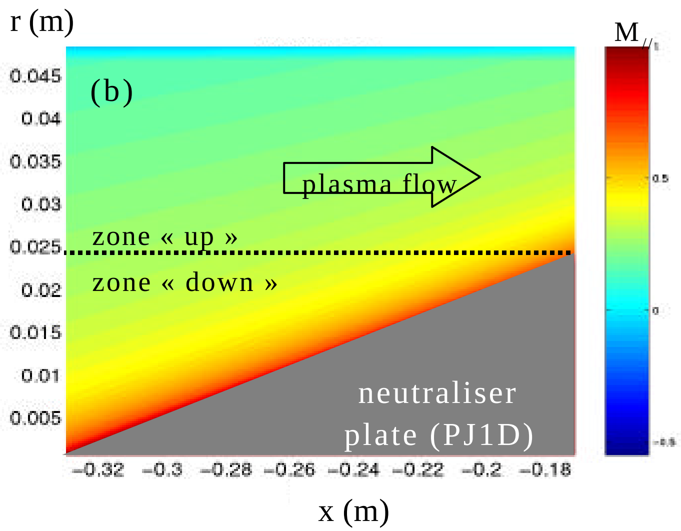
long connection

Two regions above the NP

short connection

1/ plasma flow

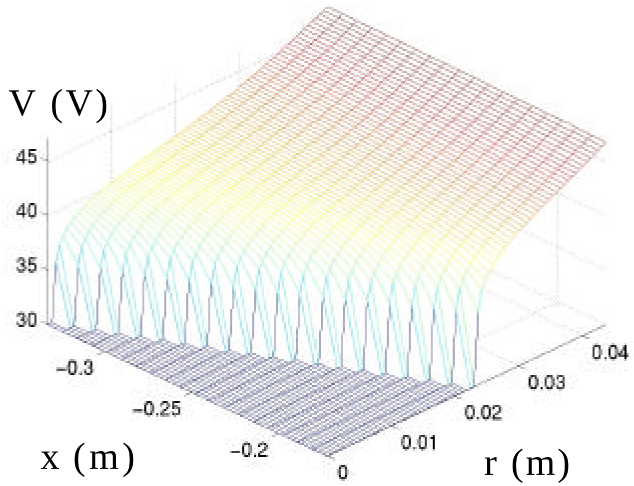




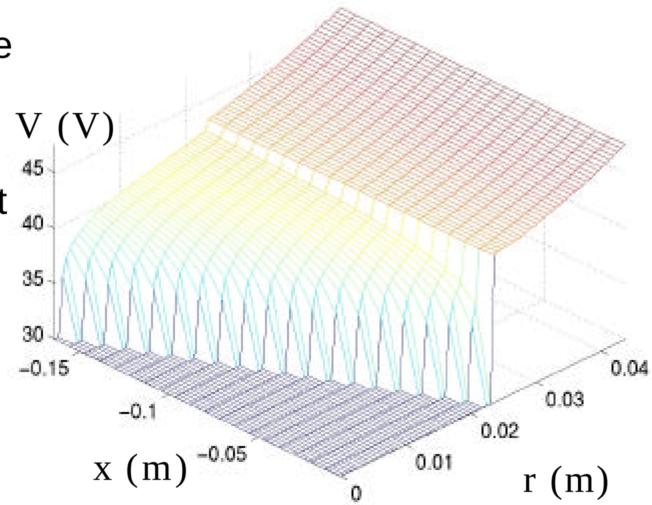
long connection

short connection

2/ Electrostatic potential

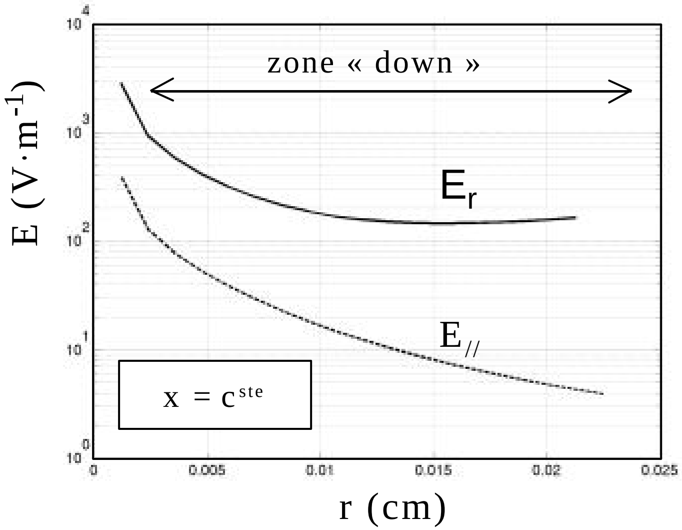


- The potentials are the same in the zone « down »
- They are different in the zone « up »



3/ Electrostatic field

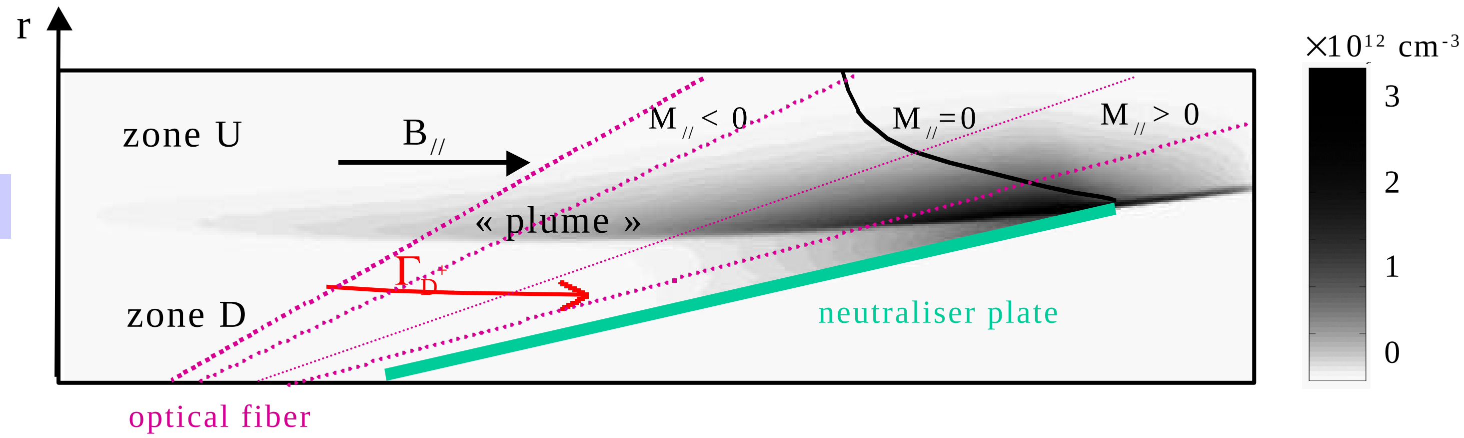
- Poloidal drift neglected in the BBQ code
- Only the parallel electric force is considered



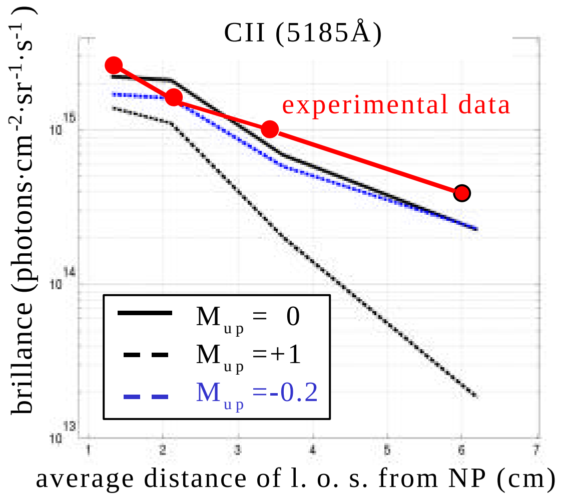
$$v_\theta = \frac{E_r \times B}{B^2}$$

$$F_{//} = q \cdot E_{//}$$

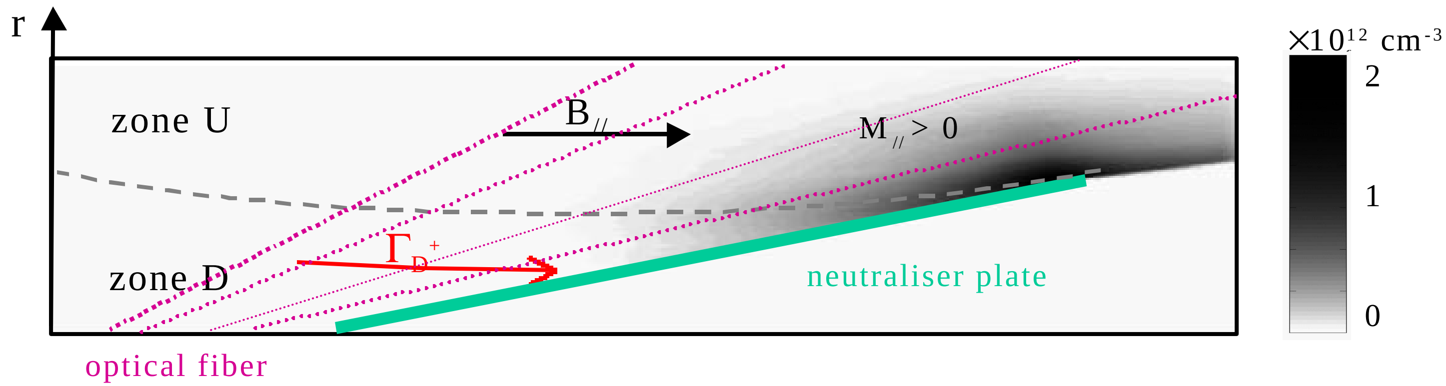
long connection



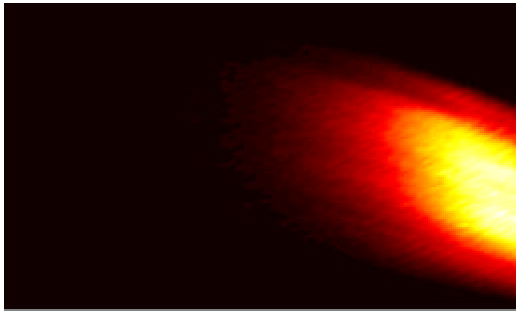
C+ DENSITY AND ASSOCIATED RADIATION CALCULATED WITH BBQ

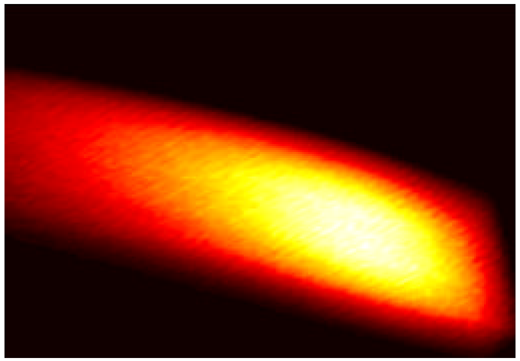


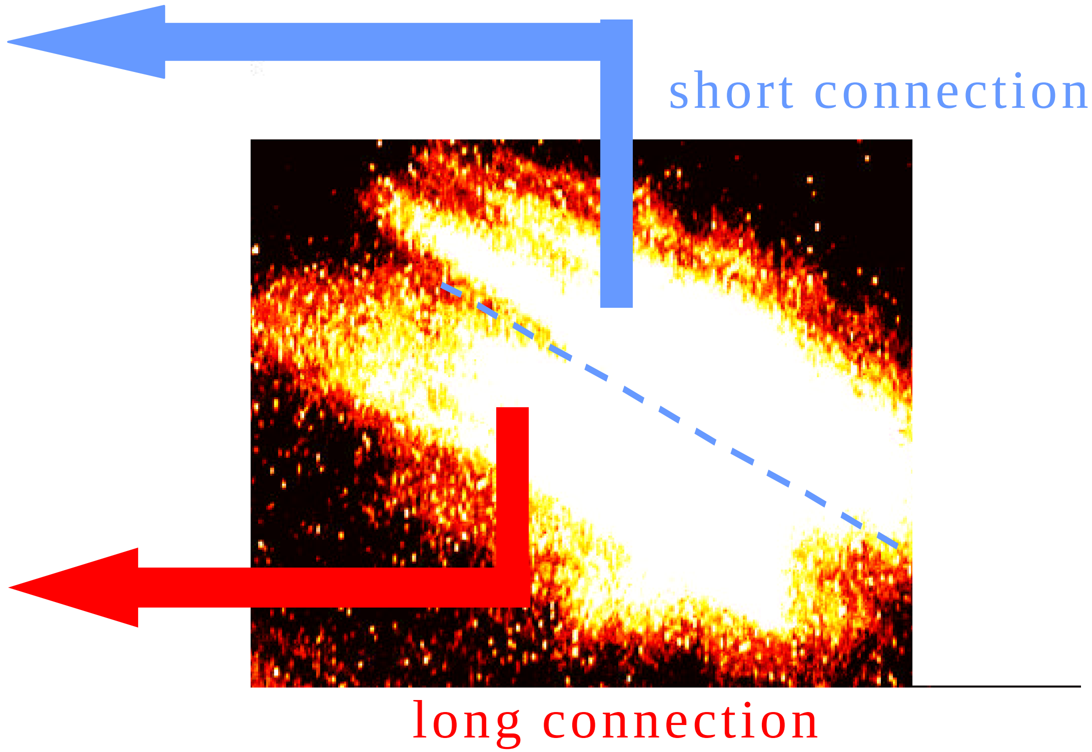
short connection



CIII RADIATION PATTER







Experimental picture of CIII (4647Å)

CONCLUSION

⑥ Accurate modelling of impurity transport above the neutralisers of the Ergodic Divertor of Tore Supra requires to include the effects of both the plasma flow and electrostatic field.

⑥ Due to the complex magnetic structure that characterized this configuration, fluid tubes with both long and short connections to the wall are present above a neutraliser.

⑥ It follows that the parallel Mach number experiences rapid variations (typically ±1) when moving away from the neutraliser plate, in agreement with Gunderstrup probe measurements (parallel Mach number and source of particles).

⑥ The radiation patterns of carbon ions (CII & CIII) show evidences of this variation of the plasma flow, as can be seen from the comparison between the simulation results and measurements (optical fibers and visible CCD camera).